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Effects of Plyometric Training and Recovery on Vertical Jump Performance and Anaerobic Power

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ABSTRACT

We examined the effects of 2 plyometric training programs, equalized for training volume, followed by a 4-week recovery period of no plyometric training on anaerobic power and vertical jump performance. Physically active, college-aged men were randomly assigned to either a 4-week (n = 19, weight = 73.4 ± 7.5 kg) or a 7-week (n = 19, weight = 80.1 ± 12.5 kg) program. Vertical jump height, vertical jump power, and anaerobic power via the Margaria staircase test were measured pretraining (PRE), immediately posttraining (POST), and 4 weeks posttraining (POST-4). Vertical jump height decreased in the 4-week group PRE (67.8 ± 7.9 cm) to POST (65.4 ± 7.8 cm). Vertical jump height increased from PRE to POST-4 in 4-week (67.8 ± 7.9 to 69.7 ± 7.6 cm) and 7-week (64.6 ± 6.2 to 67.2 ± 7.6 cm) training programs. Vertical jump power decreased in the 4-week group from PRE (8,660.0 ± 546.5 W) to POST (8,541.6 ± 557.4 W) with no change in the 7-week group. Vertical jump power increased PRE to POST-4 in 4-week (8,660.0 ± 546.5 W to 8,793.6 ± 541.4 W) and 7-week (8,702.8 ± 527.4 W to 8,931.5 ± 537.6 W) training programs. Anaerobic power improved in the 7-week group from PRE (1,121.9 ± 174.7 W) to POST (1,192.2 ± 189.1 W) but not the 4-week group. Anaerobic power significantly improved PRE to POST-4 in both groups. There were no significant differences between the 2 training groups. Four-week and 7-week plyometric programs are equally effective for improving vertical jump height, vertical jump power, and anaerobic power when followed by a 4-week recovery period. However, a 4-week program may not be as effective as a 7-week program if the recovery period is not employed.

Key Words: plyometrics, power training, vertical jump, recovery, training, power

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Introduction

The ability to produce explosive lower-body power can be an important factor in the performance of many athletic activities. Sports that require jumping, throwing, or sprinting rely heavily on the strength-speed or power of the athlete (1, 3, 19, 22). Plyometrics are used to improve power output and increase explosiveness (1) by training the muscles to do more work in a shorter amount of time (12). This is accomplished by optimizing the stretch-shortening cycle, which occurs when the active muscle switches from a rapid eccentric muscle action (deceleration) to a rapid concentric muscle action (acceleration; 14, 19, 22). The rapid eccentric movement creates a stretch reflex that produces a more forceful concentric muscle action (14, 22) than could otherwise be generated from a resting position (19). The faster the muscle is stretched, the greater the force produced, and the more powerful the muscle movement (5, 22). Plyometric exercises that exploit the stretch-shortening cycle have been shown to enhance the performance of the concentric phase of the movement (8) and increase power output (11). Traditionally, plyometric exercises include variations of bounding, hopping, and jumping drills. However, true plyometric training requires the rapid prestretch (eccentric movement) of the muscle and maximal effort of the athlete during the concentric muscle action. This type of plyometric training can be found in various forms of depth jumps and box jumps (14).

The effects of plyometric training on performance enhancement have been studied for several years. The literature spans a wide variety of assessments, including the effects of plyometrics on athletes and nonathletes (22), on aerobic performance (19), and on muscle fiber size (19), as well as its effectiveness as a stand-alone training program (6, 22) or as part of a combined program concurrent with aerobic training (19); resistance training (5, 6, 23); or electrostimulation (18). Research has found plyometrics to be effective in increasing muscle power output (12) and vertical jump performance (24).

To our knowledge, no studies have addressed the effects of different durations of a plyometric training program on improvements in power output. From a training perspective, it is important to determine the appropriate training duration necessary to elicit peak athletic performance. We also want to know if the absence of plyometric training during a recovery period would influence vertical jump performance and anaerobic power. The purpose of this study was to determine the effects of a 4-week and a 7-week plyometric training program followed by a 4-week recovery period of no plyometric training on vertical jump performance and anaerobic power.

Methods

Experimental Approach to the Problem

The present study was conducted to compare the effects of 2 equal volume plyometric training programs of different time duration on vertical jump performance and anaerobic power. A 7-week training period was selected because this length of time is similar to the length of many summer or preseason plyometric programs. Furthermore, a 7-week plyometric program is similar in length to several plyometric training studies that have shown positive effects on anaerobic performance (1, 4, 12, 16, 19, 20). A 4-week training period was utilized for comparison because it would allow for proper neuromuscular adaptations to occur. Additionally, it would be a short enough period of time for a practical comparison of the 7-week program. The training volume between the 2 groups was controlled for by equating the number of repetitions or distances covered for their respective exercises. Additional physical activity was controlled during the study as well as during the posttraining 4-week recovery period.

A control group was not utilized for this study. Numerous studies have shown that plyometrics are effective for improving anaerobic power output and vertical jump performance. The intent of this plyometric study was to compare the effects of different program durations of equal work volume on these variables. Since time, or program duration, was the independent variable, we elected not to employ a control group.

Subjects

Thirty-eight physically active young men volunteered for participation in the study. They were randomly assigned to 1 of 2 groups: a 4-week training group (n = 19) or a 7-week training group (n = 19). None of the subjects had participated in any type of structured plyometric training program prior to the study. All subjects had been consistently performing resistance training for at least 3 months before the beginning of the plyometric training. A verbal explanation of the study was given to each subject; the subject then provided written informed consent in accordance with the university guidelines for human experimentation. The subjects also completed a medical history questionnaire and were deemed healthy by the criteria set forth by the American College of Sports Medicine.

Study Design

Each subject made a total of 3 visits to the exercise physiology laboratory during this study. The first visit was for collection of pretraining data (PRE). After the initial visit, subjects were randomly assigned to a training group. The plyometric training program began within 1 week of the initial data collection. The second and third visits occurred immediately posttraining (POST) and 4 weeks posttraining (POST-4). Body composition was assessed, and the vertical jump and the Margaria power tests were administered during each of the 3 visits.

Pretest and Posttest Measurements

For each visit to the laboratory, subjects were instructed to refrain from exercise for 48 hours and caffeine 24 hours prior to testing. All tests were conducted in the following order on each visit: body composition, vertical jump, and the Margaria test.

Body composition was assessed by skinfold caliper measurement. The same trained technician measured each subject using a Lange caliper (Beta Technology Inc., Cambridge, MA). Three measurements were taken at the triceps, biceps, subscapula, abdominal, suprailiac, thigh, and calf with percent body fat (%FAT) calculated accordingly (15).

Vertical jump height was measured using the jump-and-reach method with an adjustable measuring apparatus (Vertech, Inc., Falls Church, VA). All subjects completed a controlled warm-up consisting of jogging and stretching and 3 practice jumps at submaximal effort. Each subject was allowed 3 test jumps with a 3-minute recovery between each jump. Subjects were allowed a countermovement with the arms and legs for each jump. The test-retest intraclass correlation coefficient for vertical jump height was 0.9608 (α = 0.9800). The highest jump of the 3 was used to determine vertical jump peak power via the formula of Harmon et al. (10). The test-retest intraclass correlation coefficient for vertical jump power was 0.9754 (α = 0.9875).

The Margaria staircase power test was conducted using 2 switch mats placed on the eighth and 12th steps of an 18-step staircase. Each subject completed a controlled warm-up consisting of stretching and 3 practice trials. The subjects started 2 m from the base of the stairs. The subjects then sprinted up the staircase 2 steps at a time. The switch mats automatically recorded the time taken between the subjects' fourth and sixth steps. The power output was calculated by

Table 1. Plyometric training program used in the 4-week and 7-week training groups.

Task	Weeks						
	1	2	3	4	5	6	7
4-Week group							
Vertical jumping*	15 (10)	20 (10)	25 (10)	25 (10)			
Bounding†	3 (30 m)	5 (30 m)	7 (30 m)				
Broad jumping†	5 (15 m)	5 (30 m)	7 (30 m)	8 (30 m)			
Depth jumping*	3 (5)	5 (9)	6 (15)	6 (15)			
7-Week group							
Vertical jumping*	5 (10)	9 (10)	11 (10)	13 (10)	13 (10)	17 (10)	17 (10)
Bounding†	3 (30 m)	4 (30 m)	4 (30 m)	3 (30 m)	1 (30 m)		
Broad jumping†	1 (15 m)	2 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)
Depth jumping*			2 (10)	3 (10)	6 (10)	6 (10)	7 (10)

* Number of sets followed by repetitions.
† Number of sets followed by distance.

using the following formula: $P = (W{\cdot}D)/t$, where P = power in watts, W = body weight in kilograms, D = vertical height between stairs, and t = time in seconds (17). The test-retest intraclass correlation coefficient for the Margaria staircase anaerobic power test was 0.8390 ($\alpha = 0.9124$).

After completion of all pretest measurements, subjects were randomly assigned to 1 of 2 training groups. Group 1 ($n = 19$) performed plyometric training for 4 weeks. Group 2 ($n = 19$) performed plyometric training for 7 weeks. The training programs were adjusted so that the total training volume was equal between the 2 groups.

Plyometric Training Program

The jump training exercises were performed 3 days per week. The intensity for all exercises was maximal, with changes in the number of sets and repetitions occurring with each session. The plyometric training included 2-legged vertical jumps, tuck jumps, 2-legged broad jumps, 1- and 2-legged bounding, and depth jumps completed from a height of 40 cm. During the bounding and depth jump exercises, subjects were instructed to minimize ground contact. Instructions for all other exercises were to attain maximal height during muscle movement. The recovery time between repetitions and sets was 15–30 seconds.

Equal work volume between the 2 groups was controlled by equating the total number of repetitions performed for each jumping activity and the total meters covered during the bounding. The program totals were as follows: vertical jumps = 850 repetitions, bounding = 450 m, broad jumping = 675 m, and depth jumping = 240 repetitions. Weekly summaries of each of the training programs are shown in Table 1.

Additional physical training beyond normal daily activity was not allowed for either group. The groups were also instructed to continue their usual dietary habits throughout the study. Each group completed posttest measurements 48 hours after cessation of their program and again after an additional 4-week recovery period. The same testing schedule and procedures as used for initial pretesting were followed. No control was administered for physical activity or training during the 4-week recovery period with the exception that no plyometric exercises were to be performed.

Statistical Analyses

Paired t-tests were used to identify any significant differences between groups at PRE in the dependent variables. An analysis of covariance (ANCOVA) with the PRE value as the covariate was used to determine significant differences between groups for body fat. An analysis of variance with repeated measures was used to determine significant differences for vertical jump height, vertical jump power, and anaerobic power via the Margaria test between and within the 2 training groups. Statistical significance was set at $p \leq 0.05$. All values are reported as mean ± standard deviation.

Results

Overall, subjects in the 4-week group were younger and leaner than the 7-week group. There was a significant difference in age between the 2 groups (4-week group, 20.4 ± 1.6 years vs. 7-week group, 22.7 ± 3.1 years). The results for body composition and body mass are shown in Table 2. There was also a significant difference in percent body fat between the 2 groups at the beginning of the study. There were no significant differences in body mass between the groups following training. However, there was a significant difference within both groups. The 4-week group experienced a 1.1% increase in body mass from PRE to POST. The 7-week group experienced a 1.1% increase

Table 2. Body mass and body composition in the 4-week (n = 19) and 7-week (n = 19) training groups prior to and following plyometric training (values are mean ± *SD*).

	Pre	Post	Post-4
Body mass (kg)			
4-Week	73.4 ± 7.5	74.2 ± 7.7*	75.0 ± 6.5
7-Week	80.1 ± 12.5	80.9 ± 12.9*	81.6 ± 13.2*†
% Fat			
4-Week	8.8 ± 3.2	8.6 ± 3.2	8.5 ± 2.7
7-Week	11.6 ± 4.3	11.7 ± 4.2	11.9 ± 4.3

* Significantly different than PRE.
† Significantly different than POST.

in body mass PRE to POST and a 1.9% increase from PRE to POST-4.

The results for vertical jump height are shown in Table 3. Vertical jump height decreased in both groups from PRE to POST training. There was a significant 3.5% decrease for the 4-week group and a 0.3% decrease for the 7-week group. However, both groups experienced significant increases from POST to POST-4. The 4-week group increased vertical jump height by 6.5%, POST to POST-4, whereas the 7-week group increased vertical jump height by 4.4% POST to POST-4. Overall, both groups experienced significant increases in vertical jump height when measured from PRE to POST-4. The 4-week group had a mean increase of 1.9 cm or 2.8%, whereas the 7-week group had a mean increase of 2.6 cm or 4.0%. There was no significant difference between the 2 groups for vertical jump height.

The results for vertical jump power are shown in Table 3. Vertical jump power decreased significantly PRE to POST in the 4-week group, whereas there was no change in vertical jump power from PRE to POST in the 7-week group. Both groups had significant increases from POST to POST-4; there were increases of 3.0% for the 4-week group and 2.3% for the 7-week group. Both groups also experienced increases in vertical jump power when measured PRE to POST-4. The 4-week group had a significant increase of 1.5%, and the 7-week group had an increase of 2.6%. There were no significant differences observed between groups for vertical jump power.

The results for anaerobic power are shown in Table 3. Power, as measured by the Margaria staircase test, increased in both groups from PRE to POST, but only significantly within the 7-week group. Neither group experienced significant increases in power when measured POST to POST-4. However, in both training groups, power output increased significantly when measured from PRE to POST-4. The 4-week group had a 5.8% increase in anaerobic power output, and the 7-week group had an 8.0% increase in anaerobic power output. There were no significant differences between the 2 groups for anaerobic power output.

Discussion

Plyometrics are a popular form of training for improving vertical jump performance and anaerobic power. However, little is know about the effectiveness of different training durations on these parameters. As with other forms of training, it is important to understand the necessary duration to employ in order to incur optimal results and avoid overtraining. No studies have examined the influence of recovery time before competition following this type of program.

In the present study, plyometric training programs of both 4-week and 7-week durations, equalized for training volume, resulted in significant increases in vertical jump height, vertical jump power, and power as measured by the Margaria staircase test. However,

Table 3. Vertical jump height, vertical jump power, and Margaria power in the 4-week (n = 19) and 7-week (n = 19) training groups prior to and following plyometric training (values are mean ± *SD*).

	Pre	Post	Post-4
Vertical jump height (cm)			
4-Week	67.8 ± 7.9	65.4 ± 7.8*	69.7 ± 7.6*†
7-Week	64.6 ± 6.2	64.4 ± 8.8	67.2 ± 7.6*†
Vertical jump power (W)			
4-Week	8,660.0 ± 546.5	8,541.6 ± 557.4*	8,793.6 ± 541.4*†
7-Week	8,702.8 ± 527.4	8,729.6 ± 598.4	8,931.5 ± 537.6*†
Margaria power (W)			
4-Week	1,070.6 ± 107.6	1,110.4 ± 133.1	1,132.5 ± 151.0*
7-Week	1,121.9 ± 174.7	1,192.2 ± 189.1*	1,211.9 ± 172.6*

* Significantly different than PRE.
† Significantly different than POST.

with the exception of the 7-week group's Margaria test, significant increases were only seen when used in conjunction with a 4-week recovery period. When measured immediately after cessation of the plyometric training program, vertical jump height, vertical jump power, and anaerobic power were not changed, and in some instances decreases were observed.

The use of plyometric training has been advocated for several years as a means of improving performance in sports and activities in which lower-body power plays a key role in success (6). During a plyometric movement, the muscles undergo a very rapid switch from the eccentric phase to the concentric phase. This stretch-shortening cycle decreases the time of the amortization phase that in turn allows for greater than normal power production (12, 19). The muscles stored elastic energy and stretch reflex response are essentially exploited in this manner, permitting more work to be done by the muscle during the concentric phase of movement (11, 12). Training programs that have utilized plyometric exercises have been shown to positively affect performance in power-related movements such as jumping (4, 5, 12, 14) and speed (2, 7, 20). In the present study, improvements were seen in vertical jump height, vertical jump power, and Margaria power, which support these earlier studies.

The increases in power following a plyometric training program could be due in part to increases in muscle fiber size. Improvements in muscle force production have been associated with increases in muscle fiber size (9, 21). Although not measured in the present study, earlier work in our laboratory has shown that plyometric training can result in significant increases in both Type I and Type II muscle fiber area (19). The potential increase in muscle fiber size could account for the observed increases in body mass within the groups as well since there were no changes in percent body fat within either group during the program.

Improved muscle performance due to a plyometric training program may also be due in part to increased motor unit functioning. Previous studies have indicated that neuromuscular adaptations such as increased inhibition of antagonist muscles as well as better activation and cocontraction of synergistic muscles may account for the improvements in power output (13, 16). This may partially explain the differences observed in the POST measurements between the groups. Both groups experienced a decrease in vertical jump height at POST, but only the decrease for the 4-week training group was significant. The 4-week group also experienced a significant decrease in vertical jump power at POST, whereas the 7-week group experienced an increase, although not statistically significant. In addition, both groups experienced an increase in power as measured by the Margaria test, but the increase for the 7-week group was significant, whereas the increase for the 4-week group was not. The additional 3 weeks of training time may have allowed greater neuromuscular adaptations to occur in the 7-week group that may not have been possible in the shorter training period experienced by the 4-week group.

Another possible reason for the observed decreases in the various POST measures in the 4-week training group is that the subjects were most likely in a state of overtraining. In addition to the potentially greater neuromuscular adaptations, the 7-week training group did not experience decreases (and in some cases increases) because there was less of a state of overtraining. This is probably due to the fact that more work was done in less time with the 4-week training group.

This study demonstrated the importance of a recovery period following a plyometrics program. Neither group displayed an improvement directly after the training period, with the 4-week group actually decreasing in performance. Therefore, the 4-week recovery period used in this study had a powerful effect upon performance. This study did not examine the exact amount of recovery time needed as we took measures only at posttraining and 4 weeks posttraining. It is unclear whether results would have been better with 1, 2, 3, or even more weeks of recovery than what was given. However, it is clear that a recovery period should be included following plyometrics training. In addition, when designing a plyometrics program, the duration and volume of training should determine the recovery period.

The total work volume for each program was equaled by controlling the total number of repetitions performed for each jumping activity and the total meters covered during the bounding exercises. Although the total work volume was accounted for, controlling the intensity level proved more difficult. Plyometric exercises require a maximum effort with every attempt. The perception of maximal effort is subjective. Verbal encouragement was used in an attempt to ensure maximal effort from every participant throughout the duration of the program, but objective measurements of maximal effort in this type of investigation are prohibitive.

It should also be noted that no control was administered for the activity of subjects during the 4-week recovery period. Although subjects were instructed to not perform any plyometric training during the recovery, the subjects were allowed to return to their normal activities. We assume that the subjects returned to their normal physical activity, which included resistance training.

Finally, since the criteria required only 3 months of consistent resistance training prior to inclusion in the study, the subject's fitness levels were not homogenous. These differences could have affected the levels of change observed during this study. It is possible that subjects with similar training levels may experience different effects than were seen in this study. It would be interesting to see future studies in this area conducted with a less diverse sample population.

Practical Applications

From a training perspective, it is important to determine appropriate training duration and posttraining recovery that will facilitate peak performance. Achieving maximal power production is the goal of athletes who participate in speed and power competitions. Plyometric training programs have been shown to increase an athlete's anaerobic power output. The current study provides the athlete and coach with insight into utilizing plyometric training as a means of increasing anaerobic power. These data indicate that a 4-week plyometric training program may be as effective as a 7-week plyometric training program in improving vertical jump performance, vertical jump power, and anaerobic power when a 4-week recovery period is utilized. However, a 4-week program may not be as effective as a 7-week program if the recovery period is not incorporated. In fact, a high volume of training in a short period of time, as seen in the 4-week group, significantly decreased performance when no recovery period was employed. Therefore, the posttraining recovery time available prior to competition should be a consideration in the implementation of a 4-week or 7-week plyometric training program.

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